Atmospheric dispersion
study of the Upper
Ottawa Street Landfill Site,
Hamilton, Ontario
Reference 34

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ATMOSPHERIC DISPERSION STUDY OF THE UPPER OTTAWA STREET LANDFILL SITE, HAMILTON, ONTARIO

Prepared for:

The Upper Ottawa Street Landfill Site
Study Committee

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February 1986

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1. INTRODUCTION

This report documents work carried out on the atmospheric dispersion of potential landfill emissions, and was undertaken on behalf of the Committee established to study the Upper Ottawa Landfill Site in Hamilton, Ontario. The principal purpose of the work was to estimate retrospectively the patterns of concentrations in the ambient air around the Upper Ottawa Street Site which would have resulted from atmospheric emissions from the landfill components over the most active period of its use for the disposal of industrial wastes, i.e., over the period 1976 to 1980. The estimates were to be made using mathematical dispersion modelling of the emissions, distinguishing, if possible, between the concentration patterns due to the major components of the landfill operations. Since reliable data on the quantities of contaminants emitted to the atmosphere over the period of interest were not available, the results of the analysis were expressed in terms of relative levels of ambient concentrations in the vicinity of the site, rather than absolute levels of a specific contaminant. However, the results can be readily used to derive such absolute levels, given a contaminant emission rate. This could be useful in estimating the effect of landfill emissions on neighbourhood air quality.

The scope of work for the present study encompassed the following specific elements:

a) the identification of the major components of the landfill operations representing potential sources of atmospheric emissions over the period 1976 through 1980, including their approximate locations and dimensions, for input to the mathematical dispersion modelling,

b) the establishment of a representative statistical description of wind and weather conditions at the site over the period 1976 through 1980, again for use as input to the dispersion model, and

c) mathematical dispersion modelling based on the above to estimate long-term (annual or seasonal average) patterns of atmospheric concentrations at

ground level within approximately 1 km of the site due to potential emissions from the identified landfill components.

The methodologies adopted and results obtained under each of these work elements are described in Chapters 2, 3 and 4 of this report, respectively. Chapter 5 summarizes the conclusions of the study.

2. POTENTIAL SOURCES OF EMISSIONS

An outline of the history of landfilling at the Upper Ottawa Street site has been prepared by the study committee (Ref. 1). This refers to three main areas where landfilling was carried out over the period of interest (1976 through 1980). These are shown in Figure 1 and are identified in the figure as areas 3, 4 and 5. During the period, there was little lateral expansion of the landfill. Most of the filling involved topping off of areas 3 and 4, with some new filling occurring along the eastern edge of the site (area 5). In addition, there was a complex of open lagoons, apparently used for percolation and fixation of liquid industrial wastes. Only three of these, at the west end of the comlex, appeared to be active or recently active in 1978. Most of the expansion of the landfill took place between 1954 and 1972, in area 2 on the figure.

Information compiled by the Ministry of the Environment (Ref. 2) suggests that industrial waste was received at the site, beginning in 1971. The fixation and solidification operations began in 1977. In addition, open burning of wood wastes was a routine practice, and it is possible that these wastes may have contained other material received at the site. The same Ministry source also indicates that a progressive ramp or slope method of landfilling was employed, in which material is obtained from directly in front of the working face and compacted on the waste. Typical dimensions of the working face were 2.4 m (8 ft) high by 15.2 m (50 ft) long. The face was compacted but left open at the end of each working day. Cover material was obtained from several sources and included waste foundry sand and "a felt and foam by-product".

To supplement the above sources of information on landfill operations, discussions were held with staff of the study committee and the Region of Hamilton-Wentworth. These discussions confirmed the approximate locations and sizes of the landfilling areas and indicated that most filling over the period of interest occurred over an area of approximately 20.2 ha (50 acres) in area 4 (see Figure 1), with topping off over an area of about 4.9 ha (12 acres), again mostly in area 4. Also identified was a slope of exposed waste along the north edge of the site above Redhill Creek which was subsequently covered beginning in 1978. The dimensions of the exposed slope were approximately 15.2 m (50 ft) high by 500 m (1640 ft) long. As well, discussions indicated that waste burning was restricted to the extreme east end of the site over the period in question and that there were various access roads to the working face, extending over the old landfill areas (mainly area 2 in Figure 1) as well as the active areas. The whole landfill was apparently very dusty at times, particularly in windy, dry weather.

Based on the foregoing information, five distinct areas of the landfill site were identified as potential sources of emissions to the atmosphere between 1976 and 1980. The more significant sources of volatile chemical emissions appeared to be:

a) the active landfilling area on the south side of the site bordering Stone Church Road (area 4 in Figure 1),

b) the treatment lagoons at the west end of the fixation and solidification complex, and

c) the exposed face along the north edge of the site above Redhill Creek.

Gaseous and particulate emissions due to burning were associated with:

d) the main burning area at the east end of the site.

Finally, most of the wind blown and vehicle-generated particulate matter was

associated with:

e) the whole of the recent landfill area (areas 2, 3, 4 and 5 in Figure 1)

These five areas of potential emissions are shown in Figure 2.

3. DISPERSION CLIMATOLOGY

When particulate matter or some gaseous contaminant is released to the atmosphere, it is transported in the downwind direction and, by a process of turbulent mixing with the ambient air, generally undergoes dispersion in all three dimensions. The mean direction and speed of the wind determine the direction and speed of transport of the contaminant, while dispersion is determined by the degree of turbulence present in the atmosphere. In turn, the wind conditions and degree of atmospheric turbulence at a given time and place are controlled by the large-scale weather systems in the area at the time, together with local modifying factors, such as the roughness and thermal properties of the underlying terrain and topographic features, including any mountains, valleys and bodies of water in the vicinity.

Mean wind speed and direction are relatively easy to measure and predict, but this is not the case for atmospheric turbulence. Indeed, it is even difficult to prescribe practical parameters to describe the turbulence. These difficulties have led workers in this field to adopt broad classifications of turbulence or weather types which correspond to varying degrees of dispersion. A commonly used classification scheme consists of six classes (A to F), class A corresponding to the conditions of greatest turbulent mixing and class F corresponding to conditions of least turbulent mixing. These classes can be defined in terms of the thermal stability of the atmosphere, ranging from the most unstable atmospheres (class A) to the most stable atmospheres (class F), since atmospheric turbulence is, in general, related to atmospheric stability. Atmospheric stability can be estimated from the wind speed and the solar radiation incident at the ground during the day or the surface cooling during

the night. Surface heating or cooling can be indicated by the amount of cloud cover and the time of day. For example, on clear summer days, solar heating of the ground causes an unstable layer to be established, accompanied by strong convective turbulence. By contrast, on clear nights the ground cools by radiation and a ground-based stable layer or temperature inversion may be formed in which there is little turbulence present. Neutral atmospheres (class D) are intermediate between stable and unstable conditions and are associated with strong winds and overcast skies. The clouds prevent significant surface heating or cooling, but the mechanical turbulence generated by the wind maintains good mixing.

In this study, long-term patterns of ambient air concentrations in the vicinity of the Upper Ottawa Street landfill site were simulated by mathematical dispersion modelling. The required long-term patterns are annual or seasonal averages. Therefore, in this case, the concentrations due to atmospheric emissions from the site are determined by variations in wind and weather conditions over a period of one year, or a given season, as well as the dispersion or dilution of emissions which would apply with a specific wind and weather situation. Data on such variations should include wind speed, wind direction and atmospheric stability class since, as discussed above, these are the parameters of primary interest.

The dispersion model selected for this study required the annual and seasonal wind and stability data to be presented in the form of three-way joint frequency distributions, giving the frequencies with which all combinations of wind direction, wind speed and stability conditions occur. These statistics summarize the variation in individual hourly values of the parameters over the periods in question. The closest observing station at which such data are available is at Mount Hope Airport, about 9 km southwest of the Upper Ottawa Street site. The data collected at Mount Hope are considered generally representative of conditions at the landfill site, due to the relatively close proximity of the airport and the locations of both the landfill site and the airport in similar topographic settings on top of the Niagara escarpment. However, some minor deviation can be expected at the landfill site as a result

of its proximity to the escarpment and the Redhill Creek valley. This may take the form of channelling of low-level winds along the creek valley under some light wind conditions and somewhat higher wind speeds and turbulent mixing when winds blow up and over the escarpment, i.e., from the northwest through northeast.

The annual three-way joint frequency distributions of wind speed, wind direction and stability class at Mount Hope Airport for the period 1976 to 1980 are given in an appendix to this report. In addition, these data have been further summarized in Tables 1 and 2, which show the frequencies of the different wind directions and stability classes. Table 1 indicates the following major features of the annual wind climate:

a) the prevailing (most frequently occurring) winds are from the west (14.9% of the time,

b) SW and WSW winds also occur comparatively frequently; these, combined with W winds, account for almost 40% of the data, and

c) NE and ENE winds occur less often, but with significant frequencies (16.2% combined).

The stability class frequencies in Table 2 show that:

a) neutral atmospheres (class D) are highly predominant (68.8% of the time),

b) unstable atmospheres (classes A - C) occur only 18.9% of the time, and

c) stable atmospheres (classes E and F) are the least frequent (12.8% of the time.

It is recognized, however, that this method of classifying atmospheric stability generally overestimates the frequency of neutral atmospheres and underestimates the frequencies of both stable and unstable atmospheres (Ref.

3).

Similar analyses to that shown in the appendix were obtained for each month of the year and for each season. All data were provided by the Atmospheric Environment Service of Environment Canada.

4. DISPERSION MODELLING

The Industrial Source Complex (ISC) model was used to simulate dispersion of landfill emissions and thus estimate concentrations in ambient air in the vicinity of the site. The model has been developed and approved by the U.S. Environmental Protection Agency and incorporates a number of features which make it particularly suitable for the present application. Firstly, it is specifically designed to simulate dispersion from the kind of area and line sources of interest in this study, as well as the more common point sources, i.e., chimney stacks. Secondly, it is capable of providing concentrations at a large number of receptor points in the same simulation; these receptor points are specified by the user. In its long-term mode (ISCLT), the model generates long-term concentration estimates, e.g., annual and seasonal averages, and, in so doing, uses readily available climatological data, such as the data obtained at the Mount Hope Airport.

In common with many other dispersion models, ISCLT treats the dispersion of emissions from each source as a Gaussian plume, in which the distribution of contaminants within the plume is assumed to be Gaussian in both the vertical and horizontal (crosswind) directions, i.e., the vertical and horizontal distributions follow a normal or "bell" curve. The dimensions of the plume, or the standard deviations of the distributions, are determined as functions of downwind distance and atmospheric stability class. The model performs the dispersion calculations for each source/receptor combination under all possible combinations of wind and stability conditions. It then uses the joint frequencies of these conditions (wind speed, wind direction and atmospheric stability class) over the period modelled to "weight" the calculated

concentrations. The time-averaged concentration at a given receptor is then determined as the sum of the weighted concentration values for that receptor, considering all wind and weather combinations. Further details of ISC are given in the model user's manual (Ref. 4).

The input data required by the model can be divided into three basic groups. The first includes the local meteorological and topographic data. The second describes the emission sources, and the third group specifies the receptor points at which the concentrations are to be calculated. The data used in this study are summarized below.

a) Meteorological and Topographic Input Data

The required joint frequencies of wind and stability conditions have been described earlier in this report. In fact, two sets of joint frequency data were used in the simulations. The annual data were used in the simulation of dispersion from all five landfill sources. As well, summer time data for the months of June, July and August were used in a separate simulation of potential dust emissions from the whole landfill area. This was done to determine whether or not any seasonal variations in the climatology would significantly alter the predicted concentration pattern. An additional climatic variable required by the model is the average afternoon mixing height. A value of 1000 m was used, based on published information for southern Ontario (Ref. 5). Variations in mixing height with wind speed and stability class were incorporated according to procedures given in the model user's guide (Ref. 4). Topographic relief was not included in the simulations, since potential emissions in this case occur at ground level and are not buoyant. Thus, the dispersing plumes of contaminants would essentially follow any variations in local terrain levels.

b) Emissions Input Data

The five potential sources of emissions from the landfill site have been

identified in Chapter 2 of this report. For the purposes of the model, these were represented by composites of a number of square area sources, each having dimensions of 50 m by 50 m. The five sources were modelled separately, assuming a unit rate of emission (1 g/s) of an unspecified contaminant from each, uniformly distributed over the source area.

c) Receptor Input Data

A cartesian grid of regularly spaced receptor points was specified, centred on the landfill site. In order to cover the study area of interest to the Committee, an overall grid size of 2.4 km by 2.4 km was used, with receptor points at intervals of 100 m in both the N - S and E - W directions.

The patterns of annual average ground level concentrations, corresponding to an emission rate of 1 g/s from each of the five potential sources, are shown in Figures 3 - 7. For all sources, the following characteristics of the concentration patterns are noted:

a) The highest concentrations occur to the immediate NE of the source of emissions.

b) There is a general SW - NE orientation of the concentration contours such that, at a given distance from the emissions source, receptors in the NE and SW quadrants experience higher concentrations than receptors in the SE or NW quadrants. However, the distribution in all sectors except the NW is relatively uniform beyond the first few hundred metres from the source. For example, considering emissions from the whole of the recent landfill area, the concentrations at a distance of 800 m from the centre of this area are:

Quadrant	Concentration (ug/m3/g/s)
NE	2.8
SE	1.7
SW	2.2
NW	0.5

c) There are significantly lower concentrations to the NW of the site. In some cases, these are almost an order of magnitude lower than the concentrations at equivalent distances to the NE.

Some potential emissions from the landfill site may have varied according to the time of year. For example, dust emissions can be expected to occur preferentially during the dryer summer months. Therefore, to investigate the sensitivity of the dispersion modelling results to any seasonal correlations between emissions and dispersion climatology, the analysis of dispersion from the entire landfill area was repeated using wind and weather data for the summer months only (June, July and August). The results are given in Figure 8, but show no significant variation from the results of the annual analysis of the same source (Figure 7).

As noted earlier, this study was designed to provide information on relative levels of ambient concentrations due to potential emissions from the various landfill components. Thus, the results are presented in terms of the concentration in micrograms per cubic metre of air, given an emission rate of 1 g/s of any contaminant from each source. However, if an emission rate of a particular contaminant is known, the corresponding concentrations can be estimated by simply multiplying values read from the appropriate contour plot (Figures 3 - 8) by the emission rate in grams per second. Strictly speaking,

the results would apply to the period 1976 through 1980 only, although they would also provide a good estimate of conditions over other periods, since normal year-to-year variations in dispersion climatology do not produce significant variations in predicted concentrations.

Finally, it must be emphasized that the analysis was based on the best meteorological data of the required form readily available from existing records, in this case at Mount Hope Airport. As noted above, some topographic features in the vicinity of the landfill site, i.e., the Redhill Creek valley and the Niagara escarpment, may affect local wind conditions under some circumstances and result in variations from conditions recorded at the observing station at Mount Hope. The effects of any such variations on the predicted concentration patterns cannot be quantified without further study, but they are expected to be minor.

5. CONCLUSIONS

This report has presented results of mathematical dispersion modelling of potential emissions from the Upper Ottawa Street Landfill Site over the period 1976 - 1980. Since reliable data on the actual quantities of contaminants emitted were not available, the results show only the relative levels of concentrations in the ambient air in the vicinity of the site. These results are provided for the five main components of the landfill identified as potential sources of emissions over the period in question. Absolute concentrations of a given contaminant can be estimated if the emission rate of that contaminant from any of the landfill components is known.

Two principal conclusions are drawn from the results of this study regarding the potential long-term exposures to airborne emissions from the landfill site between 1976 and 1980:

a) the highest exposures were to the immediate NE of the site, and

b) beyond the first few hundred metres from the site, exposures were relatively uniform with respect to wind direction, except in the NW quadrant, where they were significantly lower.

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4. Bowers, J.F., Bjorklund, J.R. and C.S. Cheney: Industrial Source Complex (ISC) Dispersion Model User's Guide. U.S. Environmental Protection Agency Report No. EPA-450/4-79-030, December 1979

5. Portelli, R.V.: Mixing heights, wind speeds and ventilation coefficients for Canada. Climatological Studies No. 31, Atmospheric Environment Service, Fisheries and Environment Canada, Downsview, Ont., 1977

WIND DIRECTION	FREQUENCY OF OCCURRENCE (%)
N	3.7
NNE	3.8
NE	8.1
ENE	8.1
E	3.6
ESE	1.0
SE	0.9
SSE	1.7
S	5.8
SSW	8.4
SW	11.0
WSW	13.5
W	14.9
WNW	7.2
NW	5.1
NNW	3.2

Table 1: Annual Wind Direction Frequencies at Mount Hope Airport (1976-80)

STABILITY CLASS	FREQUENCY OF OCCURRENCE (%)
A	0.8
B	5.0
C	12.5
D	68.8
E	7.3
F	5.5

Table 2: Annual Stability Class Frequencies at Mount Hope Airport (1976-80)

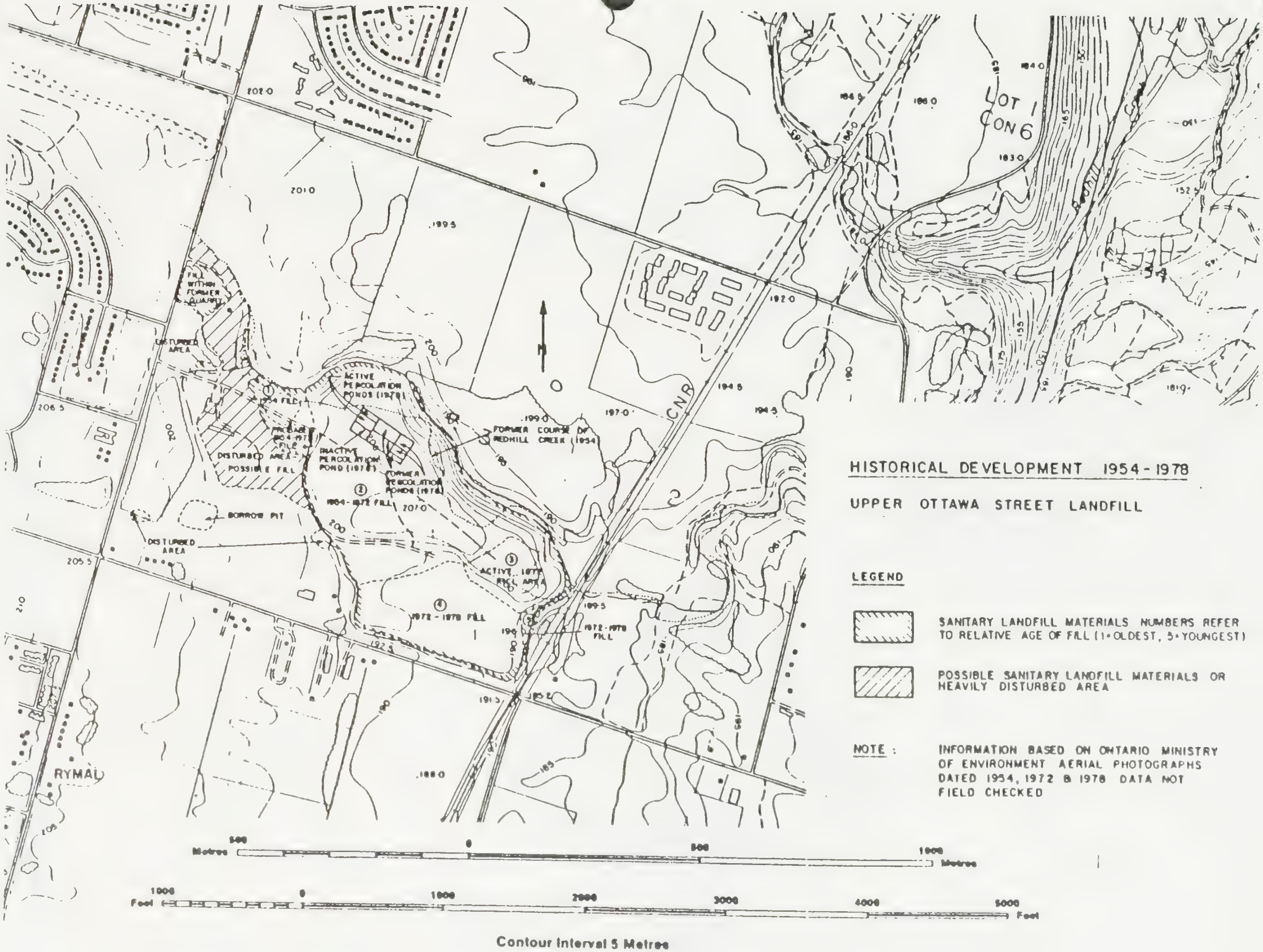

Figure 1: Historical Development of the Site (Ref. 1)

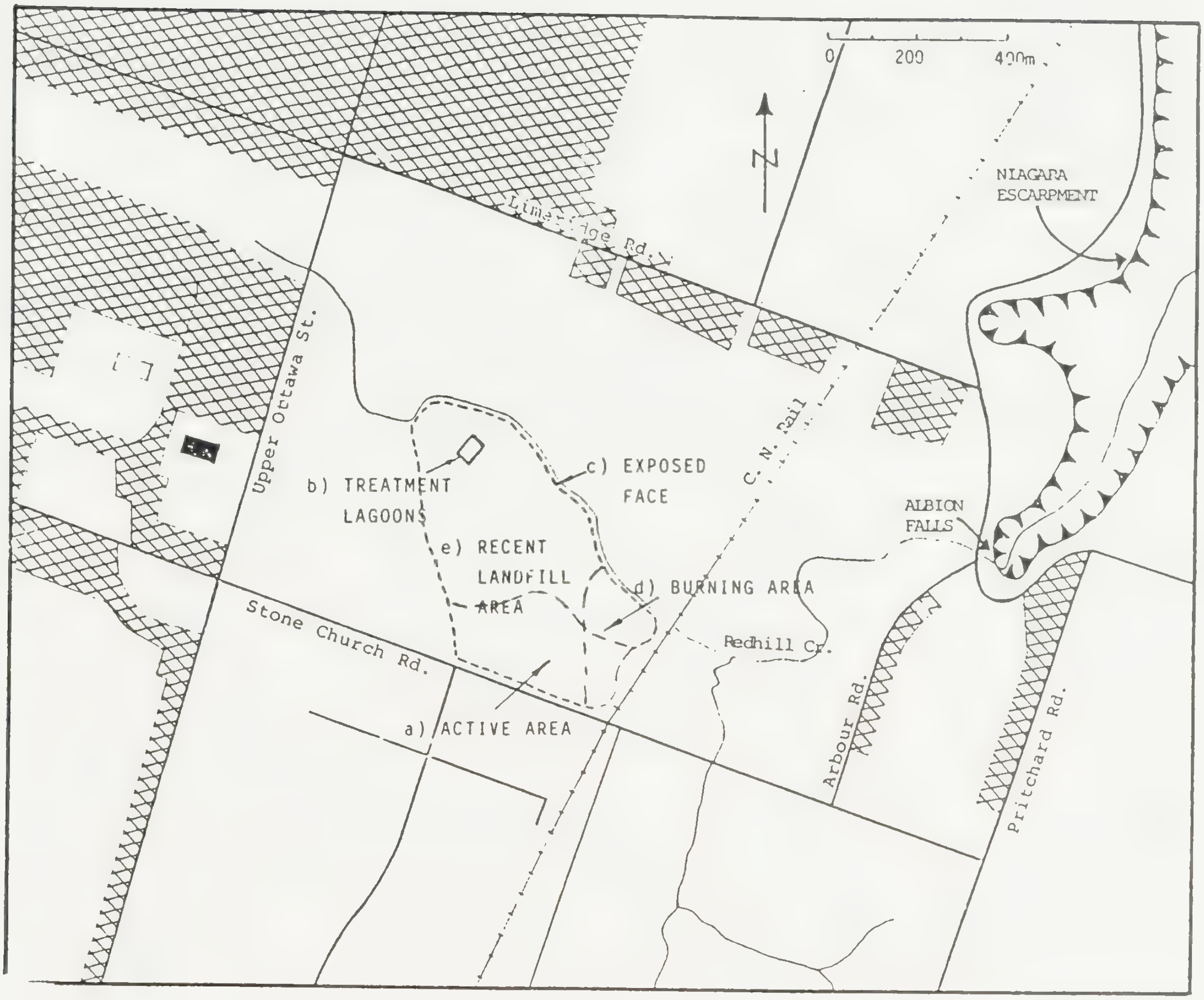

Figure 2: Landfill Components Representing Potential Sources of Emissions to the Atmosphere

Figure 3: Annual Ground Level Concentrations (ug/m3) due to Unit Emission Rate (1 g/s) from Source a) - Active Area Bordering Stone Church Road

Figure 4: Annual Ground Level Concentrations (ug/m3) due to Unit Emission Rate (1 g/s) from Source b) - Treatment Lagoons

Figure 5: Annual Ground Level Concentrations (ug/m3) due to Unit Emission Rate (1 g/s) from Source c) - Exposed Face on North Side

Figure 6: Annual Ground Level Concentrations (ug/m3) due to Unit Emission Rate (1 g/s) from Source d) - Main Burning Area on East Side

Figure 7: Annual Ground Level Concentrations (ug/m3) due to Unit Emission Rate (1 g/s) from Source e) - Total Landfill Area

Figure 8: Summer Ground Level Concentrations (ug/m3) due to Unit Emission Rate (1 g/s) from Source e) - Total Landfill Area

APPENDIX

Annual Joint Frequencies of Wind Speed, Wind Direction and Atmospheric Stability Class at Mount Hope Airport, 1976 - 80

ANNUAL — RELATIVE FREQUENCY DISTRIBUTION — STATION = HAMILTON 1976-80

SPEED(KTS)

DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.000425	0.000345	0.0	0.0	0.0	0.0	0.000770
NNE	0.000074	0.000104	0.0	0.0	0.0	0.0	0.000178
NE	0.000385	0.000207	0.0	0.0	0.0	0.0	0.000593
ENE	0.000183	0.000173	0.0	0.0	0.0	0.0	0.000356
E	0.000286	0.000069	0.0	0.0	0.0	0.0	0.000356
ESE	0.000133	0.000104	0.0	0.0	0.0	0.0	0.000237
SE	0.000109	0.000069	0.0	0.0	0.0	0.0	0.000178
SSE	0.000158	0.000138	0.0	0.0	0.0	0.0	0.000296
S	0.000469	0.000242	0.0	0.0	0.0	0.0	0.000711
SSW	0.000292	0.000242	0.0	0.0	0.0	0.0	0.000533
SW	0.000366	0.000345	0.0	0.0	0.0	0.0	0.000711
WSW	0.000410	0.000242	0.0	0.0	0.0	0.0	0.000652
W	0.000662	0.000345	0.0	0.0	0.0	0.0	0.001007
WNW	0.000267	0.000207	0.0	0.0	0.0	0.0	0.000474
NW	0.000198	0.000276	0.0	0.0	0.0	0.0	0.000474
NNW	0.000143	0.000035	0.0	0.0	0.0	0.0	0.000178
TOTAL	0.004560	0.003144	0.0	0.0	0.0	0.0	

RELATIVE FREQUENCY OF OCCURRENCE OF A STABILITY = 0.007704

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH A STABILITY = 0.003213

ANNUAL RELATIVE FREQUENCY DISTRIBUTION STATION = HAMILTON 1976-80

DIRECTION	SPEED(KTS) 0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.001520	0.001347	0.000449	0.0	0.0	0.0	0.003316
NNE	0.001044	0.000829	0.000587	0.0	0.0	0.0	0.002460
NE	0.000967	0.001900	0.001486	0.0	0.0	0.0	0.004353
ENE	0.000952	0.001762	0.001209	0.0	0.0	0.0	0.003923
E	0.001487	0.001762	0.000622	0.0	0.0	0.0	0.003871
ESE	0.000804	0.000726	0.000138	0.0	0.0	0.0	0.001667
SE	0.000654	0.000760	0.000207	0.0	0.0	0.0	0.001622
SSE	0.000891	0.000829	0.000449	0.0	0.0	0.0	0.002169
S	0.001164	0.001244	0.001140	0.0	0.0	0.0	0.003548
SSW	0.000682	0.001382	0.000829	0.0	0.0	0.0	0.002893
SW	0.001172	0.001313	0.001106	0.0	0.0	0.0	0.003590
WSW	0.001162	0.001935	0.001347	0.0	0.0	0.0	0.004444
W	0.001328	0.002418	0.001486	0.0	0.0	0.0	0.005232
WNW	0.000944	0.000967	0.001036	0.0	0.0	0.0	0.002946
NW	0.000991	0.000691	0.000484	0.0	0.0	0.0	0.002166
NNW	0.000787	0.000933	0.000484	0.0	0.0	0.0	0.002204
TOTAL	0.016549	0.020798	0.013059	0.0	0.0	0.0	

RELATIVE FREQUENCY OF OCCURRENCE OF B STABILITY = 0.050406

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH B STABILITY = 0.003593

ANNUAL RELATIVE FREQUENCY DISTRIBUTION STATION = HAMILTON 1976-80

SPEED(KTS)

DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.000765	0.001762	0.002522	0.000553	0.0	0.0	0.005602
NNE	0.000418	0.001382	0.003040	0.000553	0.0	0.0	0.005393
NE	0.000829	0.002349	0.005666	0.001347	0.000173	0.0	0.010364
ENE	0.000756	0.002384	0.006564	0.001762	0.0	0.0	0.011466
E	0.000909	0.002384	0.002557	0.000138	0.0	0.0	0.005988
ESE	0.000499	0.001071	0.000518	0.0	0.0	0.0	0.002088
SE	0.000197	0.000760	0.000656	0.0	0.0	0.0	0.001614
SSE	0.000392	0.000795	0.001244	0.000104	0.0	0.0	0.002534
S	0.000703	0.002246	0.005735	0.001347	0.000069	0.0	0.010100
SSW	0.000704	0.001900	0.006184	0.001451	0.000069	0.000035	0.010343
SW	0.001050	0.002626	0.005355	0.002073	0.000380	0.000207	0.011691
WSW	0.000579	0.002868	0.006737	0.001797	0.000242	0.0	0.012222
W	0.001380	0.004249	0.009777	0.002487	0.000380	0.0	0.010274
WNW	0.000582	0.001486	0.004146	0.001313	0.000207	0.000035	0.007766
NW	0.000453	0.001002	0.003351	0.000760	0.000207	0.0	0.005774
NNW	0.000320	0.000829	0.002729	0.000380	0.0	0.0	0.004258
TOTAL	0.010537	0.030092	0.066782	0.016065	0.001727	0.000276	

RELATIVE FREQUENCY OF OCCURRENCE OF C STABILITY = 0.125479

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH C STABILITY = 0.003973

ANNUAL RELATIVE FREQUENCY DISTRIBUTION STATION = HAMILTON 1976-80

SPEED(KTS)

DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.001124	0.004180	0.006979	0.007532	0.000518	0.000380	0.020713
NNE	0.000899	0.003144	0.008775	0.010054	0.001658	0.000311	0.024841
NE	0.001161	0.006702	0.018794	0.023700	0.005528	0.002038	0.057924
ENE	0.001332	0.008015	0.017205	0.021454	0.005735	0.002868	0.056609
E	0.001513	0.005942	0.006599	0.004768	0.001036	0.000104	0.019962
ESE	0.000602	0.001624	0.001900	0.000380	0.0	0.0	0.004506
SE	0.000253	0.001416	0.002038	0.000795	0.0	0.0	0.004502
SSE	0.000497	0.002211	0.003524	0.002211	0.000311	0.0	0.008754
S	0.001291	0.004940	0.012161	0.012817	0.001693	0.000691	0.033594
SSW	0.000902	0.004699	0.017723	0.026740	0.006599	0.001347	0.058011
SW	0.000910	0.005804	0.017067	0.038176	0.012783	0.005597	0.080337
WSW	0.001025	0.006357	0.019347	0.047988	0.019243	0.009846	0.103806
W	0.001493	0.008188	0.023977	0.047469	0.018449	0.007608	0.107384
WNW	0.000598	0.003593	0.010986	0.027535	0.006979	0.001969	0.051661
NW	0.000585	0.002902	0.007981	0.019036	0.003904	0.001175	0.035582
NNW	0.000877	0.003351	0.004906	0.009052	0.001278	0.000380	0.019844
TOTAL	0.015063	0.073069	0.179962	0.299706	0.085714	0.034514	

RELATIVE FREQUENCY OF OCCURRENCE OF D STABILITY = 0.688029

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH D STABILITY = 0.006046

ANNUAL RELATIVE FREQUENCY DISTRIBUTION STATION = HAMILTON 1976-80

SPEED(KTS)

DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.0	0.001416	0.002004	0.0	0.0	0.0	0.003420
NNE	0.0	0.001347	0.001693	0.0	0.0	0.0	0.003040
NE	0.0	0.002142	0.001935	0.0	0.0	0.0	0.004077
ENE	0.0	0.003386	0.002004	0.0	0.0	0.0	0.005390
E	0.0	0.002038	0.000415	0.0	0.0	0.0	0.002453
ESE	0.0	0.000726	0.000104	0.0	0.0	0.0	0.000829
SE	0.0	0.000553	0.000035	0.0	0.0	0.0	0.000587
SSE	0.0	0.001347	0.000173	0.0	0.0	0.0	0.001520
S	0.0	0.003662	0.002004	0.0	0.0	0.0	0.005666
SSW	0.0	0.003213	0.002971	0.0	0.0	0.0	0.006184
SW	0.0	0.004319	0.003939	0.0	0.0	0.0	0.008257
WSW	0.0	0.003662	0.005182	0.0	0.0	0.0	0.008844
W	0.0	0.004077	0.005562	0.0	0.0	0.0	0.009639
WNW	0.0	0.001900	0.003731	0.0	0.0	0.0	0.005631
NW	0.0	0.001520	0.003006	0.0	0.0	0.0	0.004526
NNW	0.0	0.000933	0.002004	0.0	0.0	0.0	0.002937
TOTAL	0.0	0.036241	0.036759	0.0	0.0	0.0	

RELATIVE FREQUENCY OF OCCURRENCE OF E STABILITY = 0.073000

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH E STABILITY = 0.0

ANNUAL — RELATIVE FREQUENCY DISTRIBUTION — STATION = HAMILTON 1976-80

SPEED(KTS)

DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.001235	0.002211	0.0	0.0	0.0	0.0	0.003446
NNE	0.000743	0.001244	0.0	0.0	0.0	0.0	0.001987
NE	0.001456	0.002315	0.0	0.0	0.0	0.0	0.003770
ENE	0.001451	0.001589	0.0	0.0	0.0	0.0	0.003041
E	0.001920	0.001486	0.0	0.0	0.0	0.0	0.003406
ESE	0.000605	0.000449	0.0	0.0	0.0	0.0	0.001054
SE	0.000233	0.000173	0.0	0.0	0.0	0.0	0.000405
SSE	0.000675	0.000622	0.0	0.0	0.0	0.0	0.001297
S	0.001688	0.002487	0.0	0.0	0.0	0.0	0.004176
SSW	0.002176	0.003662	0.0	0.0	0.0	0.0	0.005838
SW	0.001683	0.003628	0.0	0.0	0.0	0.0	0.005311
WSW	0.001638	0.003835	0.0	0.0	0.0	0.0	0.005473
W	0.002190	0.005148	0.0	0.0	0.0	0.0	0.007338
WNW	0.001306	0.002384	0.0	0.0	0.0	0.0	0.003689
NW	0.001129	0.001831	0.0	0.0	0.0	0.0	0.002960
NNW	0.000807	0.001382	0.0	0.0	0.0	0.0	0.002189
TOTAL	0.020936	0.034445	0.0	0.0	0.0	0.0	

RELATIVE FREQUENCY OF OCCURRENCE OF F STABILITY = 0.055381

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH F STABILITY = 0.008188